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Geochemistry and origin of plagiogranites from the Eldivan Ophiolite, Çankırı (Central Anatolia, Turkey)

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Abstract: The Eldivan Ophiolite, exposed around Ankara and Çankırı cities, is located at the central part of the İzmir-Ankara-Erzincan Suture Zone (IAESZ). It represents fragments of the Neotethyan Oceanic Lithosphere emplaced towards the south over the Gondwanian continent during the Albian time. It forms nearly complete series by including tectonites (harzburgites and rare dunites), cumulates (dunites, wherlites, pyroxenites, gabbro and plagiogranites) and sheeted dykes from bottom to top. Imbricated slices of volcanic-sedimentary series and discontinuous tectonic slices of ophiolitic metamorphic rocks are located at the base of tectonites. Plagiogranitic rocks of the Eldivan Ophiolite are mainly exposed at upper levels of cumulates. They are in the form of conformable layers within layered diorites and also dikes with variable thicknesses. Plagiogranites have granular texture and are mainly composed of quartz and plagioclases. The occurrences of chlorite and epidote revealed that these rocks underwent a low grade metamorphism. Eldivan plagiogranites have high SiO_2 content (70–75 %) and low K_2O content (0.5–1 %) and display flat patterns of REE with variable negative Eu anomalies. LREE/HREE ratio of these rocks varies between 0.2–0.99. All members of the Eldivan rocks have high LILE/HFSE ratios with depletion of Nb, Ti and P similar to subduction related tectonic settings. Geochemical modelling indicates that the Eldivan plagiogranites could have been generated by 50–90 % fractional crystallization and/or 5–25 % partial melting of a hydrous basaltic magma.

Key words: Eldivan Ophiolite, Early Jurassic, plagiogranite, fractional crystallization, partial melting.

Introduction

Turkey is an East-West oriented peninsula formed by collision of the Gondwanian and Eurasian continents. The Neotethys was the ocean between these continents in Mesozoic times (Şengör & Yılmaz 1981; Stöcklin 1984; Stampfli 2000; Robertson et al. 2006). The suture zone that was formed due to the closure of the Neotethys and the collision of the Laurasia and Gondwana continents passes through the north of Turkey and generally coincides with the east–west trending İzmir-Ankara-Erzincan ophiolitic belt (Fig. 1a). The zone starting from north of İzmir is approximately 2000 kilometers long and continues the Sevan-Akera Zone to the northeast and Zagros-Neyriz-Oman Zone towards to the southeast (Okay & Tüysüz 1999; Tekin et al. 2002). The Eldivan Ophiolite taking place in middle parts of IAESZ, represents the remnants of the Neotethyan oceanic lithosphere, which rifted in the Upper Triassic and closed in the Cretaceous–Lower Paleocene (Bailey & McCallien 1953; Akyürek 1981; Tankut 1984; Bragin & Tekin 1996; Göncüoğlu et al. 2003, 2010; Rojay et. al. 2004; Gökten & Floyd 2006; Çakır 2009; Tekin et al. 2009). It consists of peridotites, gabbroic rocks, isolated dolerite dykes, sheeted dykes and large amounts of plagiogranites (e.g. Dilek & Thy 2006; Dangerfield et al. 2011).

Our study focuses on plagiogranites of the Eldivan Ophiolite, located at upper levels of a nearly complete ophiolitic sequence at the central parts of IAESZ. In this paper we document geological structure of the Eldivan Ophiolite and plagiogranites with detailed investigations on different rock groups. A combination of petrographic and whole rock data was used to interpret the classification, tectonic settings and origin of Eldivan plagiogranites.

Geological outline and field relationships

The Eldivan Ophiolite, exposed around Ankara and Çankırı cities, is located in the central part of the İzmir-Ankara-Erzincan Suture Zone (IAESZ). It forms a nearly complete sequence by including tectonites (harzburgites and rare dunites), cumulates (dunites, wherlites, pyroxenites, gabbro and plagiogranites) and sheeted dykes from bottom to top. Imbricated slices of volcanic-sedimentary series and discontinuous tectonic slices of ophiolitic metamorphic rocks are located at the base of the tectonites. Amphibolites, calcshists and rarely observed micaschists and quartzites are the main metamorphic rocks. The $^{40}Ar/^{39}Ar$ ages of these rocks range between 177.08 ± 0.96 Ma and 166.9 ± 1.1 Ma (Early Jurassic) and are interpreted as the time of an intra-oceanic subduction (Çelik et al. 2011). A volcanic-sedimentary unit is located at the base of the tectonites as intercalations of sedimentary (radiolarian cherts, pelagic limestones and shales) and basic volcanic rocks. The younger levels of the volcanic-sedimentary units have been dated as Berriasian–Barremian (Early Cretaceous) based on the radiolarian fossil content (Tekin et al. 2012). Therefore the Eldivan Ophiolite is interpreted as a fragment of the Neotethyan oceanic lithosphere formed during the Late Triassic and Early Cretaceous time. The emplacement time of

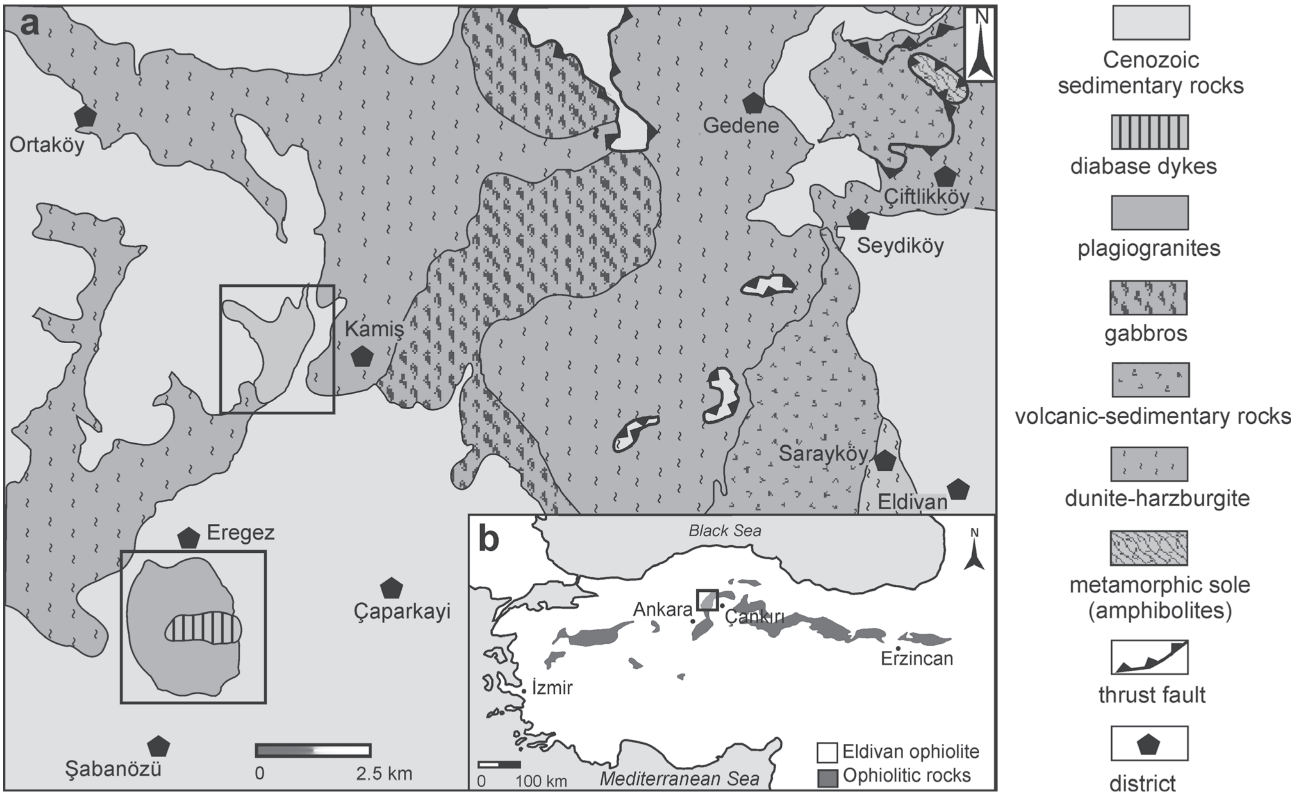

Fig. 1. a — The delineation of the İzmir-Ankara-Erzincan Suture Zone; **b** — Geological map of the Eldivan ophiolite (modified from Akyürek et al. 1979).

the Eldivan Ophiolite over the Gondwanian continent is reported as Albian (Akyürek 1981). Tectonites represent the major unit of the Eldivan Ophiolite (Fig. 1b) and are composed of harzburgites with regular dunite and pyroxenite bands, irregular dunite zones and chromite deposits. Foliation, lineation and folds in tectonites are tracers of plastic deformation. Gabbro, pyroxenite veinlets and isolated diabase dykes cut tectonites along these foliation planes. Cumulates overlying the tectonites have the form of undeformed dunite, wherlite, pyroxenite and gabbro intercalations (transition zone). Layered gabbros, flaser gabbros, massive gabbros, diorites and plagiogranites are distinguishable towards the top of the cumulates. Plagiogranites are mainly exposed in the upper parts of cumulates as light coloured tabular levels and/or pockets within the mafic layered diorites. They are also observed as dykes cutting gabbro and diorites with variable thicknesses (Fig. 2a). The reported radiometric age of the plagiogranites in the Eldivan Ophiolites is 179 ± 15 Ma

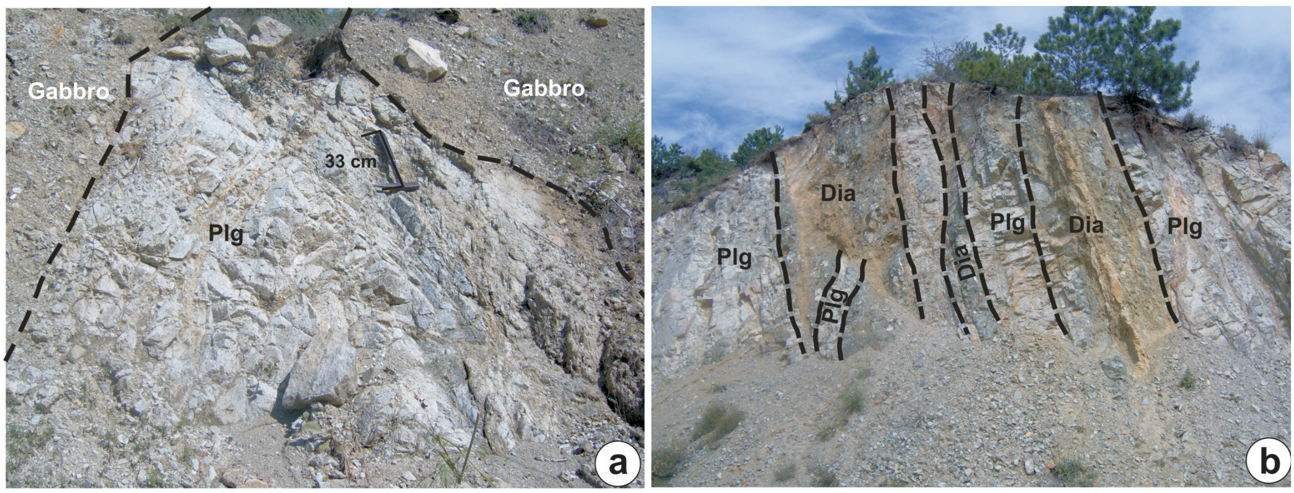

Fig. 2. Field photographs of plagiogranites. **a** — contact of plagiogranites and gabbros; **b**— diabase dykes in plagiogranites.

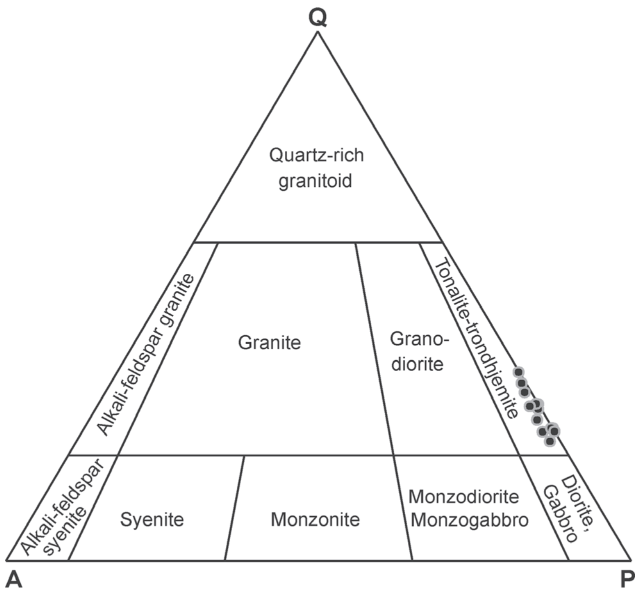

Fig. 3. Classification of the Eldivan plagiogranites in Q-A-P diagram (Streckeisen 1973) by using normative mineralogical compositions.

(Early Jurassic) (Dilek & Thy 2006). E-W trending sheeted dykes with chilled margins cut the massif gabbros, diorites and plagiogranites (Fig. 2b). Their thicknesses range between 30 cm–3 m.

Petrography

Plagiogranites are mainly composed of quartz (25–30 %) and plagioclase (45–55 %), and rarely contain pyroxene (3–5 %), biotite (2–4 %), hornblende (5–7 %), epidote (6–8 %) and K-feldspar (<1%). They have hypidiomorphic granular texture with fine to medium sized grains (0.3–1 mm) and classified as tonalite-trondhjemite (Fig. 3). Moreover, porphyritic granular texture could also be observed (Fig. 4a)

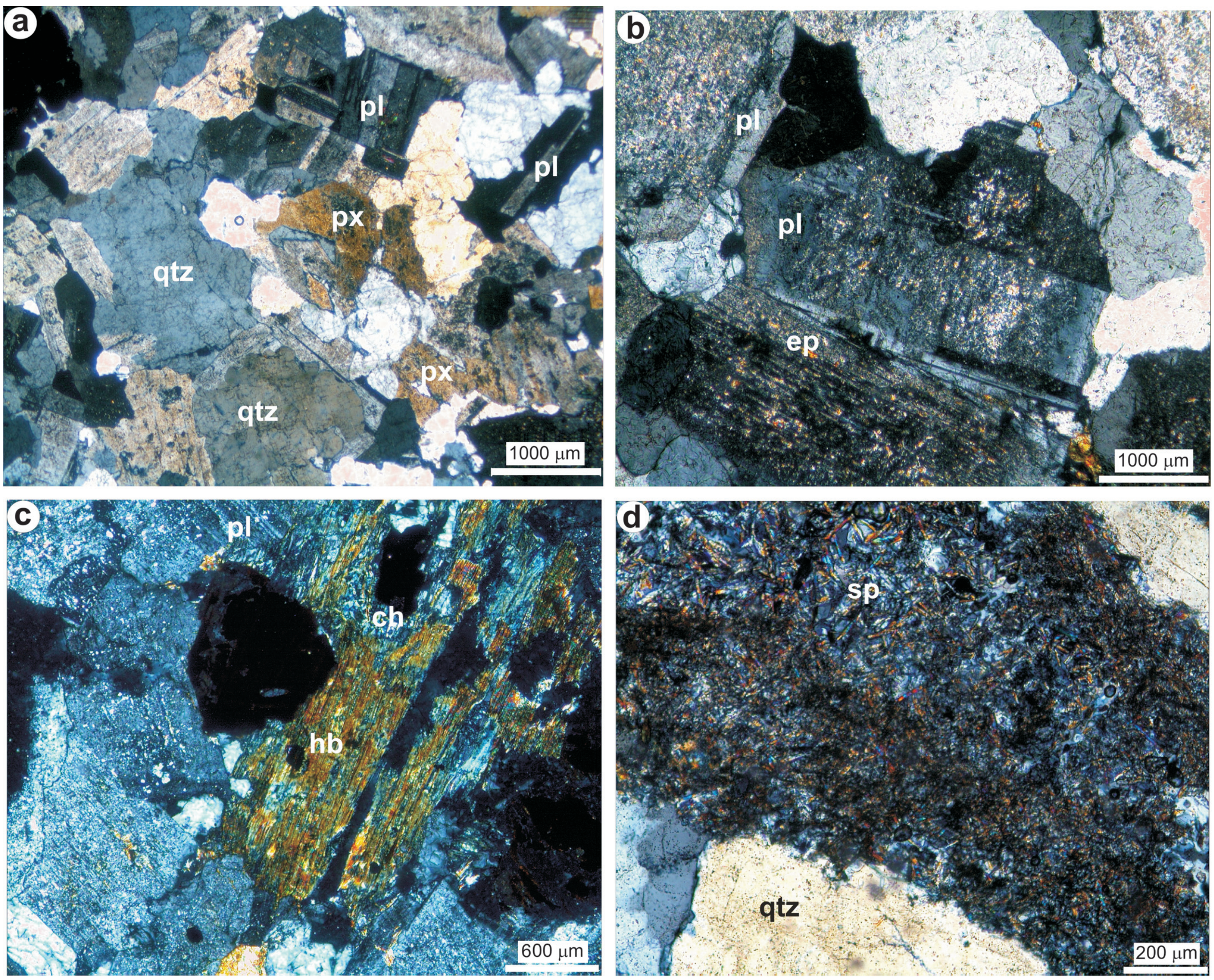

Fig. 4. Microphotographs of plagiogranites in the Eldivan Ophiolite. **a** — Granular texture of plagiogranites with quartz, plagioclase and pyroxene minerals; **b** — Epidote transformation from inner parts of plagioclases; **c** — Hornblende transformed in part to chlorite; **d** — Accessory sphene in plagiogranites. **qtz** — quartz, **pl** — plagioclase, **px** — pyroxene, **ep** — epidote, **hb** — hornblende, **ch** — chlorite.

in plagiogranites. Plagioclases are found as subhedral minerals with medium grain size (0.5–1 mm). Quartz is generally found as an anhedral mineral and rarely displays recrystallization textures. Plagioclase-quartz intergrowths (granophyric-micrographic textures) are common and interpreted as primarily formed textures during eutectic crystallization (Coleman & Donato 1979). Plagioclase is saussuritized or sericitized. Most of them are partly transformed to sericite and epidote minerals (Fig. 4b). Amphibole is partly and/or completely replaced by actinolite, epidote, and chlorite (Fig. 4c). Biotite is a primary phase commonly replaced by chlorite. Most of the original pyroxene is replaced by amphibole but some clinopyroxene is still preserved. These alterations reveal that hydrothermal alteration possibly resulting from an ocean floor water circulation has affected the plagiogranite rocks (Spooner & Fyfe 1973; Lecuyer et al. 1990) or they have undergone weak greenshist metamorphism (Coleman & Donato 1979). Accessory minerals are mainly zircon, apatite and sphene (Fig. 4d).

Whole rock geochemistry

Whole rock major element compositions of 13 plagiogranites (Table 1) were determined by ICP-Emission Spectrometry following a lithium metaborate/tetraborate fusion and dilute nitric acid digestion at ACME (Canada) analytical laboratories. Trace element contents (Table 2) were determined in the same laboratory by ICP Mass Spectrometry following a lithium metaborate/tetrabortate fusion and nitric acid digestion.

In terms of standard chemical classification, using the stable element ratios such as Zr/TiO_2 diagram (Winchester & Floyd 1977), plagiogranites fall within the rhyolite and dacite fields (Fig. 5). They have SiO_2 contents of 71.21–74.67 wt. % and Al_2O_3 contents of 13.17–15.71 wt. % (Table 1). These rocks are enriched in Na_2O (3.51–6.85 wt. %) and depleted in K_2O (0.12–0.40 wt. %) with the compositions plotted in the trondhjemites and tonalities fields of the An-Ab-Or (O'Connor 1965) diagram (Fig. 6) and oceanic plagiogranites in the K_2O vs. SiO_2 diagram (Fig. 7). In terms of trace elements, plagiogranites display low Rb and Sr concentrations, and Ba and Nb contents are relatively low for granitoids (Table 2). Eldivan plagiogranites display similar features with the other Tethys ophiolites and plotted within the volcanic arc and border of the oceanic ridge suites in tectonic discrimination diagrams (Fig. 8).

The chondrite-normalized REE patterns of the Eldivan plagiogranites are shown with Troodos Oceanic Plagiogranites, Precambrian Saganaga Tonalite and Jabal Turf Continental Granophyre in Figure 9a. The REE concentrations of the Eldivan plagiogranites have similar trends with Troodos oceanic plagiogranite and display flat patterns with variable negative Eu anomalies. The HREE contents of the Eldivan rocks are slightly enriched over LREE contents with La/Yb_N ranging between 0.2–0.99. The presence of the negative Eu anomaly in most of the Eldivan rocks indicates removal of plagioclase by fractional crystallization or partial melting of a rock in which feldspar is retained in the source. Relatively low content of normative anortite when compared with the experimentally obtained felsic melts (Koepke et al. 2004) (Fig. 6) could also be related to plagioclase fractionation.

The multi-element spider diagram of Eldivan plagiogranites normalized to normal mid-ocean ridge basalt (N-MORB) (Fig. 9b) reveals enrichment of Large Ion Lithophile Elements (LILE) over High Field Strength Elements (HFSE). The most striking feature of the diagram is the depletion of Nb, Ti and P. These negative anomalies are likely to be related

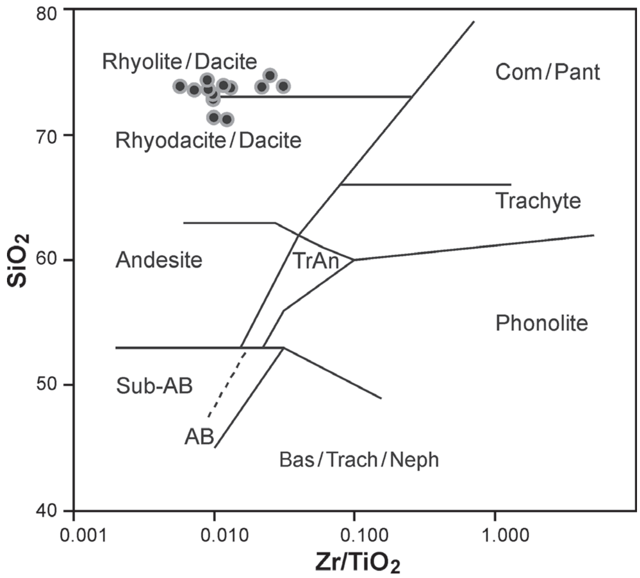

Fig. 5. Plagiogranites plotted in SiO_2 vs. Zr/TiO_2 diagram (Winchester & Floyd 1977).

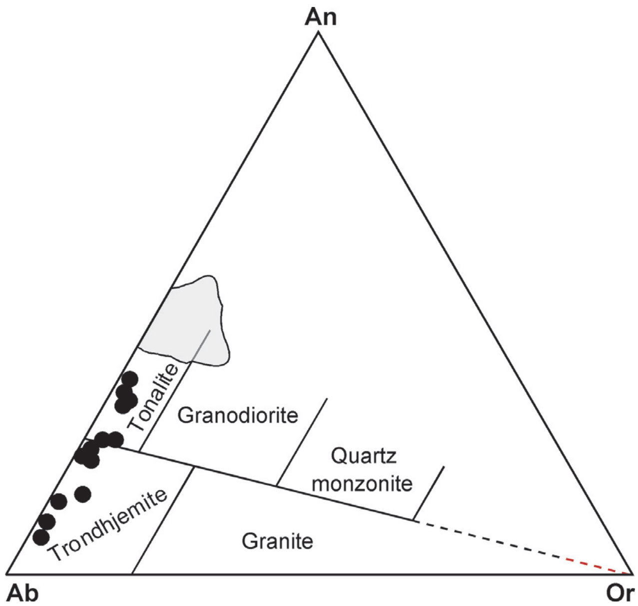

Fig. 6. Feldspar normative An-Ab-Or diagram (after O'Conner 1965) for the Eldivan plagiogranites. The field of experimental melt compositions for felsic melts produced during the partial melting of hydrated gabbro was taken from Koepke et al. (2004). **To** — tonalite, **Tdh** — trondjemite, **Gd** — granodiorite, **Gr** — granite.

Table 1: Major element contents of Eldivan plagiogranites.

Sample	SB-1	SB-5	SB-22	SB-6	SB-27	ELD-14B	ELD-14F	ELD-16	ELD-21	ELD-26	ELD-29	SBK-3B	SBK-14B	ELD-14e
SiO_2	73.7	73.19	73.52	73.71	73.83	73.83	74.67	72.86	73.89	71.31	71.21	74.26	73.82	48.77
TiO_2	0.72	0.67	0.48	0.59	0.46	0.36	0.25	0.25	0.27	0.84	0.8	0.9	0.51	0.23
Al_2O_3	13.85	13.25	14.52	13.85	13.08	14.82	13.75	13.34	15.71	13.82	14.69	13.17	14.34	16.26
FeO	2.3	1.14	1.72	1.21	1.41	1.64	1.05	2.22	2.32	1.88	1.6	0.86	1.76	8.41
MnO	0.04	0.02	0.04	0.06	0.07	0	0.05	0.1	0.04	0.08	0.04	0.07	0.04	0.14
MgO	0.38	0.75	0.35	1.96	0.81	0.16	0.85	3	0.39	0.52	0.74	0.48	0.43	9.95
CaO	0.87	5.62	2.67	2.61	3.67	3.93	2.87	3.49	1.51	3.48	4.61	4.09	2.9	12.59
Na_2O	5.83	4.05	5.37	5.3	6.02	4.29	4.64	3.51	4.56	6.85	4.56	5.03	4.87	1.08
K_2O	0.2	0.31	0.25	0.17	0.12	0.21	0.4	0.15	0.39	0.14	0.33	0.2	0.35	0.04
P_2O_5	0.07	0.07	0.08	0.05	0.08	0.04	0.07	0.03	0.05	0.05	0.04	0.04	0.04	0.03
LOI	1.9	1.1	0.8	0.7	0.9	1.3	1.4	0.9	1.1	1.3	0.9	0.8	1.1	2.3
Total	98.63	98.79	98.81	99.52	99.45	99.28	98.69	98.97	99.13	99.31	99.05	99.1	98.76	99.78
Q	36.14	38.36	35.15	33.89	30.77	39.23	39.73	38.82	41.92	24.36	33.78	37.09	37.63	
C	2.63	0.00	0.75	0.32	0.00	0.485	0.63	1.13	5.16	0.00	0.00	0.00	0.77	
Ab	49.33	34.27	45.44	44.85	50.94	36.30	39.26	29.70	38.58	57.96	38.58	42.56	41.21	
An	3.86	17.06	12.72	12.62	8.31	19.24	13.78	17.12	7.16	6.55	18.64	12.77	14.13	
Wo	0.00	4.02	0.00	0.00	2.64	0.00	0.00	0.00	0.00	3.37	1.19	2.99	0.00	
Il	1.37	1.27	0.91	1.12	0.87	0.68	0.48	0.48	0.51	1.60	1.52	1.71	0.97	
Ap	0.17	0.17	0.19	0.12	0.19	0.10	0.17	0.07	0.12	0.12	0.10	0.10	0.10	
Bi	1.98	2.81	2.46	1.50	1.12	2.13	3.69	1.36	3.90	1.35	3.07	1.75	3.41	
Ho	0.00	1.11	0.00	0.00	4.70	0.00	0.00	0.00	0.00	3.67	1.75	0.14	0.00	

Table 2: Trace element content of Eldivan plagiogranites.

Sample	SB-1	SB-5	SB-22	SB-6	SB-27	ELD-14B	ELD-14F	ELD-16	ELD-21	ELD-26	ELD-29	SBK-3B	SBK-14B	ELD-14e
Sc	11.0	13.00	11.00	12.00	16.00	12.00	10.00	21.00	15.00	15.00	18.00	14.00	11.00	46
Ba	24.0	23.00	14.00	27.00	24.00	16.00	48.00	62.00	72.00	56.00	49.00	31.00	19.40	41
Co	18.9	26.30	28.00	23.40	15.00	29.90	29.80	27.20	20.40	23.00	14.00	16.10	12.90	50.5
Ga	12.70	13.80	12.70	12.00	14.60	12.30	13.90	13.50	13.30	13.10	12.30	12.60	3.80	11.9
Hf	2.40	2.80	2.10	2.80	2.20	3.00	2.20	2.90	2.70	2.73	3.30	3.10	2.81	0.3
Nb	1.20	1.10	1.20	1.30	2.40	1.30	1.70	1.90	1.30	2.70	2.40	1.30	2.30	0.2
Rb	3.80	1.20	3.50	2.10	1.10	1.30	4.90	3.10	4.70	2.00	4.30	1.80	4.50	1.7
Sr	108.50	108.00	88.00	93.10	144.50	74.90	124.10	117.30	110.70	99.00	128.00	79.60	90.20	84.8
Ta	0.30	0.40	0.50	0.50	0.20	0.40	0.40	0.20	0.40	0.14	0.16	0.30	0.70	nd
Th	0.40	0.50	0.60	0.70	0.40	0.50	0.20	0.00	0.50	0.40	0.60	0.60	0.30	nd
U	0.20	0.30	0.40	0.30	0.20	0.30	0.20	0.00	0.20	0.20	0.40	0.30	0.60	nd
V	7.00	35.00	6.00	<8	23.00	4.00	11.00	104.00	23.00	29.00	17.00	<8	320.10	230
W	178.4	246.30	237.30	330.10	157.50	284.60	255.90	115.20	260.80	185.80	194.40	224.40	99.90	35.9
Zr	66.80	65.90	34.10	76.50	55.00	78.80	63.80	24.70	83.60	84.00	96.00	80.80	29.00	7.7
Y	21.60	32.20	39.20	27.90	22.00	33.30	18.50	16.90	20.60	19.40	22.60	34.20	32.30	5.7
La	0.60	2.50	6.90	2.80	1.80	3.70	1.60	1.00	1.80	6.10	4.80	2.70	6.80	0.3
Ce	2.00	7.10	11.60	7.50	6.20	9.60	5.40	3.00	5.00	4.60	5.41	8.30	9.09	1
Pr	0.38	1.25	2.07	1.22	0.93	1.66	0.89	0.49	0.73	0.51	0.62	1.35	1.50	0.16
Nd	1.90	7.10	10.80	6.60	5.60	8.20	4.70	2.70	3.60	5.78	10.60	8.60	2.31	1
Sm	0.83	2.52	3.43	2.58	2.09	3.10	1.86	1.13	1.03	2.14	3.36	3.07	0.78	0.45
Eu	0.25	0.61	0.69	0.79	1.03	0.67	0.60	0.47	0.42	0.73	1.20	0.90	0.64	0.22
Gd	1.24	3.90	5.76	3.75	3.08	4.34	2.41	1.66	1.22	3.82	4.28	4.77	1.77	0.74
Tb	0.27	0.81	1.55	0.77	0.60	0.86	0.52	0.35	0.23	0.57	1.27	0.97	1.46	0.15
Dy	1.70	4.86	7.39	4.95	3.96	5.10	2.93	2.29	1.18	3.83	8.72	6.12	4.12	0.98
Ho	0.38	1.14	1.66	1.09	0.84	1.21	0.62	0.51	0.29	0.84	1.92	1.44	2.31	0.22
Er	1.27	3.34	6.30	3.23	2.52	3.68	1.74	1.61	0.96	2.42	5.85	4.47	3.55	0.68
Tm	0.21	0.54	1.00	0.51	0.40	0.61	0.30	0.24	0.16	0.37	0.68	0.68	0.62	0.1
Yb	1.60	3.51	4.63	3.55	2.46	3.85	2.01	1.63	1.70	2.26	4.21	4.17	4.56	0.7
Lu	0.26	0.55	0.93	0.56	0.40	0.61	0.30	0.25	0.17	0.35	0.86	0.70	0.20	0.11
Mo	0.30	0.30	0.20	0.20	0.20	0.30	0.30	0.00	0.30	0.30	0.30	0.20	25.30	0
Cu	19.60	4.30	0.90	0.30	16.80	0.80	1.40	3.00	1.00	18.10	21.60	93.10	0.50	39.5
Pb	0.40	0.10	0.30	0.20	0.40	0.20	0.50	0.40	0.30	0.20	0.40	0.10	0.70	0.2
Zn	28.00	3.00	23.00	6.00	30.00	0.00	33.00	24.00	27.00	18.00	36.00	20.00	1.00	11
Ni	0.50	1.60	0.30	0.30	2.70	0.10	0.20	6.80	0.60	2.70	1.30	1.10	1.20	6.4

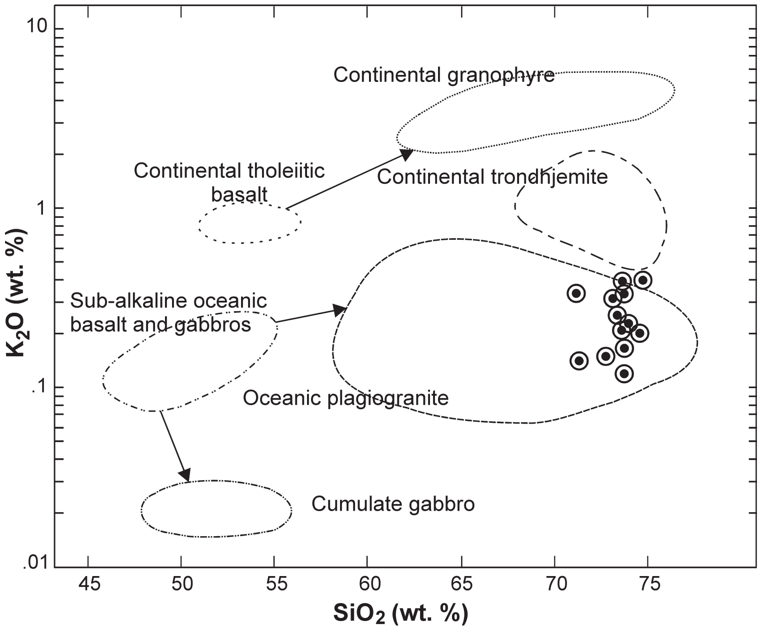

Fig. 7. Semi logarithmic K_2O–SiO_2 diagram of Eldivan plagiogranites (Coleman 1977). Continental rock types are also shown for comparison.

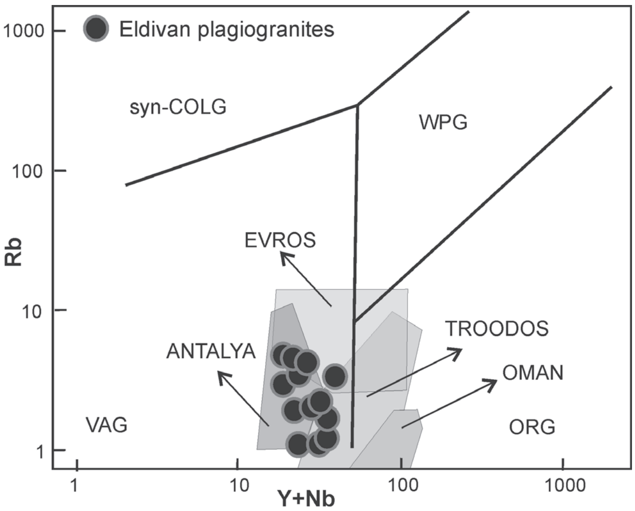

Fig. 8. Tectonic environment diagrams of the Eldivan plagiogranites; Rb versus Y+Nb diagram (after Pearce et al. 1984). **Data source:** Troodos — Aldiss (1978); Semail — Alabaster et al. (1982); Antalya — Cocherie (1978) and Magganas (2007). **ORG** — ocean ridge granite, **VAG** — volcanic arc granite, **WPG** — within plate granite, **syn-COLG** — syn-collisional granite.

to hornblend, Fe-Ti oxides and apatite fractionation, respectively. The high ratio of LILE/HFSE and especially pronounced depletion of Nb are characteristics of arc-related ophiolitic plagiogranites.

Classification of Eldivan plagiogranites as identical rocks in Figures 3, 5, 6 and also well organised REE-MORB normalised patterns with a few exceptions suggest that most of the elements have not been mobilized significantly, although these rocks have experienced isochemical alteration.

Discussion

The IAESZ is a major tectonic boundary in northern Turkey, which (e.g. Rojay 2013) separates the Pontides, to the north, from the Anatolide–Tauride and the Kırşehir blocks to the south (e.g. Şengör & Yılmaz 1981; Dilek & Moores 1990; Okay & Tüysüz 1999; Rojay 2013; Çelik et al. 2013). Çelik et al. (2013) state that it has a critical position between the Jurassic–Lower Cretaceous Neotethyan ophiolites of the Balkans and those in Armenia and Iran. The Eldivan Ophiolite, part of the Ankara mélange within the center of the IAESZ is composed of various types of igneous rocks and displays N-MORB, OIB and supra-subduction magmatic affinities (e.g. Dilek et al. 2007; Dangerfield et al. 2011; Çelik et al. 2013). The negative Nb anomalies shown in Figure 9 are diagnostic for arc-related petrogenesis in the source of the Eldivan plagiogranites. It is consistent with the earlier geochemical and tectonic models and suggests that the plagiogranites from the Eldivan Ophiolite are likely to have evolved in a supra-subduction zone environment (e.g. Tankut et al. 1998; Dilek et al. 2007; Dangerfield et al. 2011; Çelik et al. 2013). A recent study of Çelik et al. 2013 proposed that the Eldivan Ophiolite makes the bridge between the discontinuous outcrops of Upper Jurassic Ophiolite of the Hellenide–Dinarides to the West and those of Armenia and Iran to the East.

In this part we discuss the plagiogranite formation in the Eldivan Ophiolite from a gabroic parent which has a subduction related magmatic affinity.

Plagiogranite petrogenesis

The term *plagiogranite* is used for leucocratic rocks containing mainly quartz, plagioclases and rarely ferromagnesian minerals (Coleman & Peterman 1975; Coleman & Donato 1979; Amri et al. 1996; Rao et al. 2004; Kour & Mehta 2005). Several models have been put forward to explain the plagiogranite formation. Koepke et al. (2007) summarized the generally accepted models. The first one involves late stage differentiation of low-K tholeiitic MORB magmas (Coleman & Peterman 1975; Coleman & Donato 1979; Pallister & Knight 1981; Floyd et al. 2000). The second model assumes hydrous partial melting of gabbro or similar melts in a MOR setting (Gerlach et al. 1981; Spulber & Rutherford 1983; Floyd et al. 2000). Liquid immiscibility in an evolved MORB liquid has been suggested as third scenario for the plagiogranite generation (Phillpotts 1976; Dixon & Rutherford 1979; Floyd et al. 2000). In our subsequent discussion we assess the viability of the first two processes in explaining the major element and REE data of plagiogranites.

Fractional crystallization

Differentiation of MORB or low K-tholeiite type parental melt has been proposed to explain the origin of plagiogranites in several ophiolitic complexes. In order to see if the

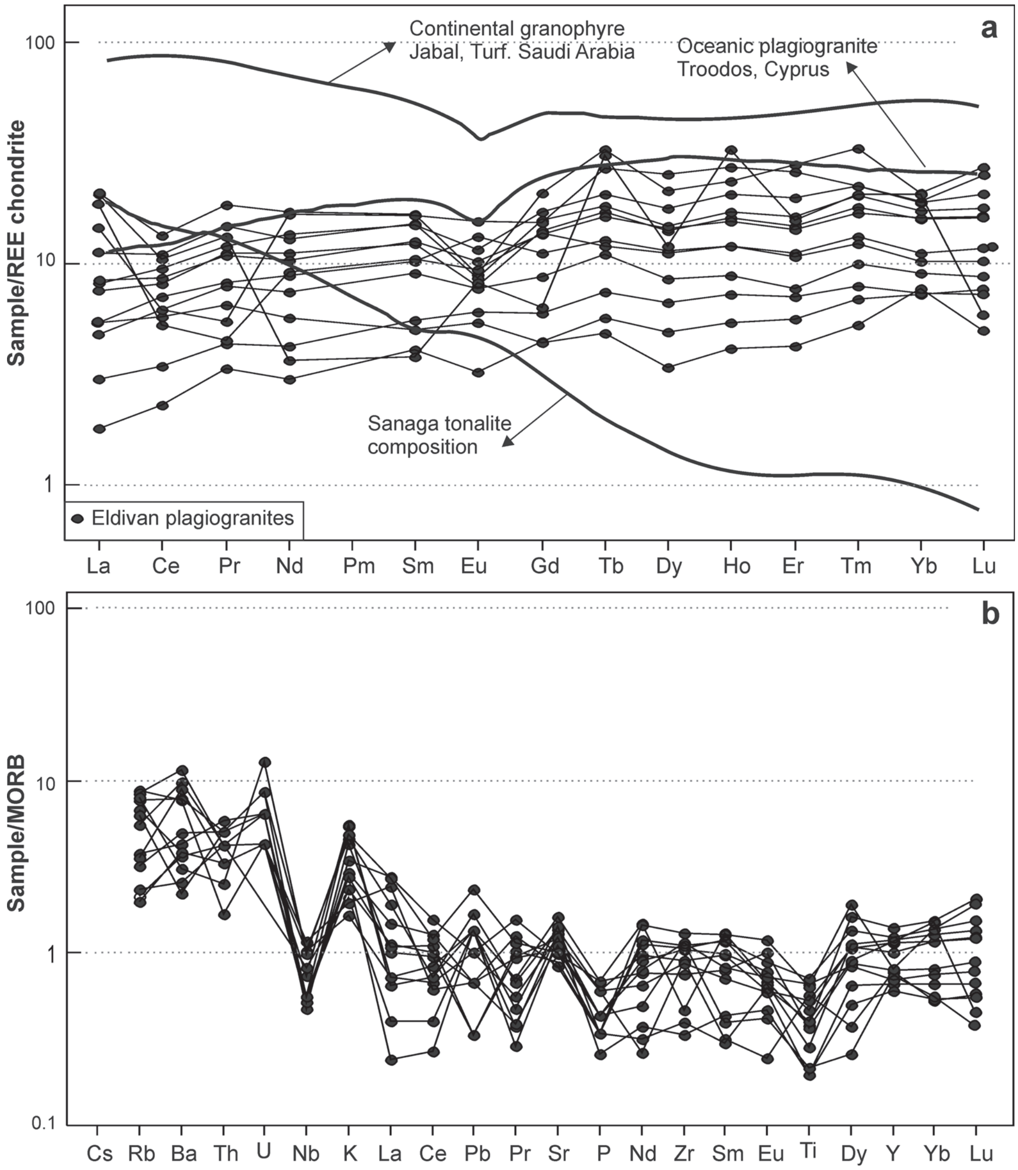

Fig. 9. Chondrite normalized (**a**) and N-MORB normalized (**b**) spider diagrams of Eldivan Plagiogranites. **Data sources:** Continental granophyre samples — Coles (1974); oceanic plagiogranite — Kay & Senechal (1976); Saganata tonalite — Arth & Hanson (1972).

Eldivan plagiogranites originate from the late stage differentiation product of a gabbroic/basaltic magma, we used MELTS code of Ghiorso & Sack (1995). MELTS allows the modelling of liquid lines of descent of silicate magmas as a function of P, T, fO_2 and H_2O. In our modelling we used a tholeiitic gabbroic sample with a MgO content of 9.95 wt. % (Sample Eld 14e, Table 1) which is the most mafic member of the Eldivan Ophiolite. The crystallization temperature interval is 1000–800 °C and fO_2 value is chosen as QFM + 1. The modelling performed under hydrous and anhydrous conditions. The modelled dry and hydrous differentiation trends and Eldivan plagiogranites are shown in Figure 10. The best match between modelled and observed differentiation trends was obtained for P = 1 kbar, H_2O = 1 wt. %. In all major element contents plagiogranites seem to be a result of fractionation of a gabbroic end member under hydrous conditions. On this basis, namely that some plagiogranites could be generated by fractional crystallization of gabbros, a further attempt was done by using the normalized REE patterns of the Eldivan gabbro and Eldivan plagiogranites and the equation of modal Rayleigh fractionation. The model is carried out for a hydrous gabbro "parent" with a mineral composition and proportions of $0.1_{olivine}+0.5_{plagioclase}+0.3_{clinopyroxene}+0.1_{hornblende}$ (Sample Eld 14e). As seen in Figure 11, the modelled patterns comprise 50–90 % fractionation of a tholeiitic gabbro and fall within the plagiogranite envelope with the development of a small Eu anomaly.

Partial melting

Numerous experimental studies on the dehydration melting of amphibolites or basaltic melts have been performed

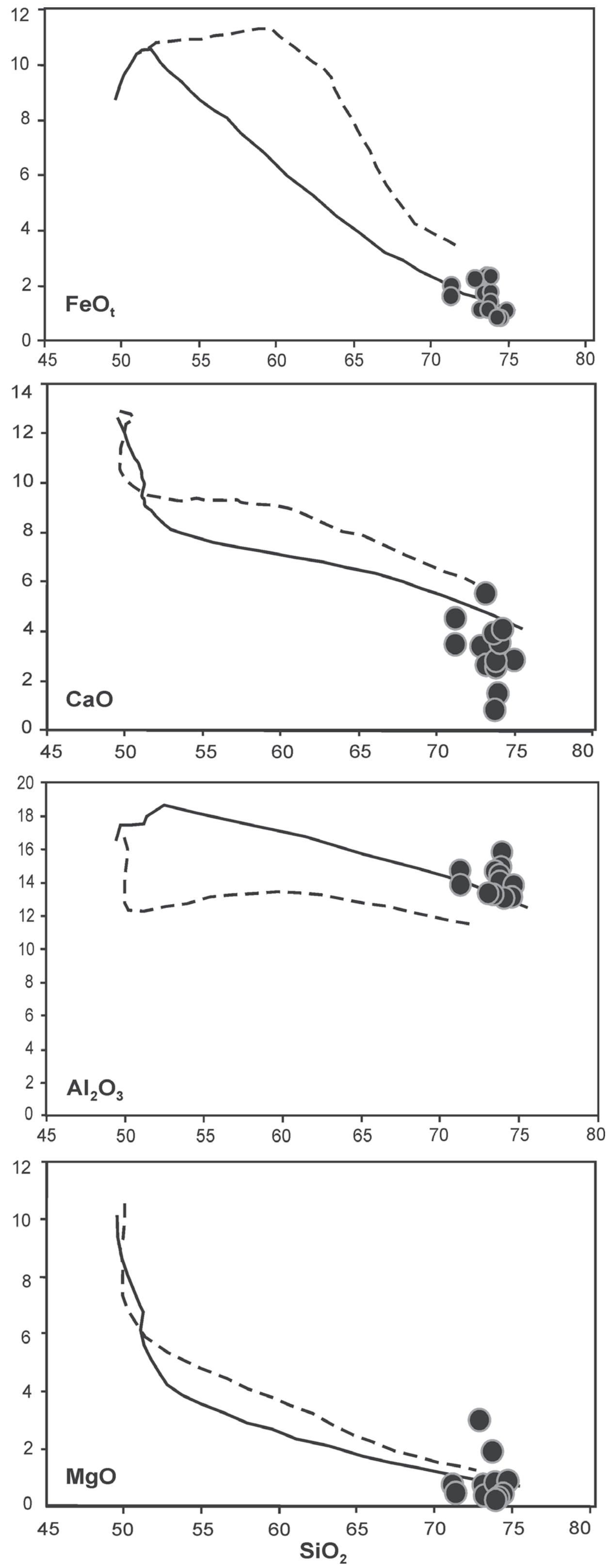

Fig. 10. FeO^T, CaO, Al_2O_3 and MgO vs. SiO_2 for Eldivan plagiogranites and MELTS (Ghiorso & Sack 1995) fractional crystallization modelling curves. Crystallization temperature interval is 1000–800 °C and fO_2 value is chosen as QFM +1. Calculation parameters; 1 kbar hydrous (1 % H_2O) (black continuous curve), 1 kbar anhydrous (0 % H_2O) (black dashed curve).

(e.g. Spulber & Rutherford 1983; Beard & Lofgren 1991; Wyllie & Wolf 1993). These studies reveal that partial melting of basic rocks could produce silicic melts. Firstly, Koepke et al. (2004) performed hydrous partial melting experiments at low pressures under slightly oxidizing conditions on different oceanic gabbros. The result of this experimental study indicates that plagiogranites can be generated by low degree partial melting of oceanic gabbros. To test the hypothesis that plagiogranites may form by partial melting of gabbroic source rocks under hydrous conditions, modal equilibrium batch partial melting equations (Shaw 1970) were applied to the REE data of the Eldivan Ophiolites. A tholeiitic gabbroic sample (Sample Eld 14e, Table 2) was taken as a mafic end member due to its primitive nature for the modelling. Mineral/liquid partition coefficients for REE are taken from Rollingson (1993). The partial melting model of gabbro and Eldivan plagiogranites are given in Figure 12. The results of the model reveal that 5, 10, 15 % partial melting of the gabbroic source can reproduce some of the Eldivan plagiogranites, although the model cannot generate the plagiogranites with higher REE content.

In summary, both fractional crystallization and partial melting of gabbroic 'parent material' could provide the initial generation of plagiogranitic melts. However, the former process is more likely to produce most of the range of plagiogranite compositions observed.

Conclusions

The İzmir-Ankara-Erzincan suture zone in northern Turkey is a remnant of the İzmir-Ankara-Erzincan Ocean branch of the Neotethys that formed during collision of the Kırşehir block and Tauride-Anatolide platforms. This suture zone consists of ophiolitic material and forms the Ankara mélange in its central parts.

The Eldivan Ophiolite is a part of Ankara mélange representing remnants of Neotethyan oceanic lithosphere which rifted during Late Triassic. It consists of peridotites, gabbroic rocks, dolerite dykes, sheeted dykes and a large amount of plagiogranites. The plagiogranites of the Eldivan Ophiolite have the form of conformable layers within the layered diorites and also dykes with variable thicknesses. They have granular texture and display traces of low grade metamorphism in their mineralogical content. Tectonic discrimination diagrams and high LILE/HFSE ratios with pronounced Nb depletion indicate the presence of subduction component related to island arc activity in the source region of the Eldivan plagiogranites. In terms of their origin, plagiogranitic melts could have been generated by either fractional crystallization under moderately hydrated (H_2O = 1 wt. %) and QFM +1 (quartz-fayalite-magnetite) conditions at 1 kbar pressure with 50–90 % fractionation or 5–25 % partial melting of a gabbroic material. However, the fractional crystallization model is more likely to produce most of the range of observed plagiogranite compositions.

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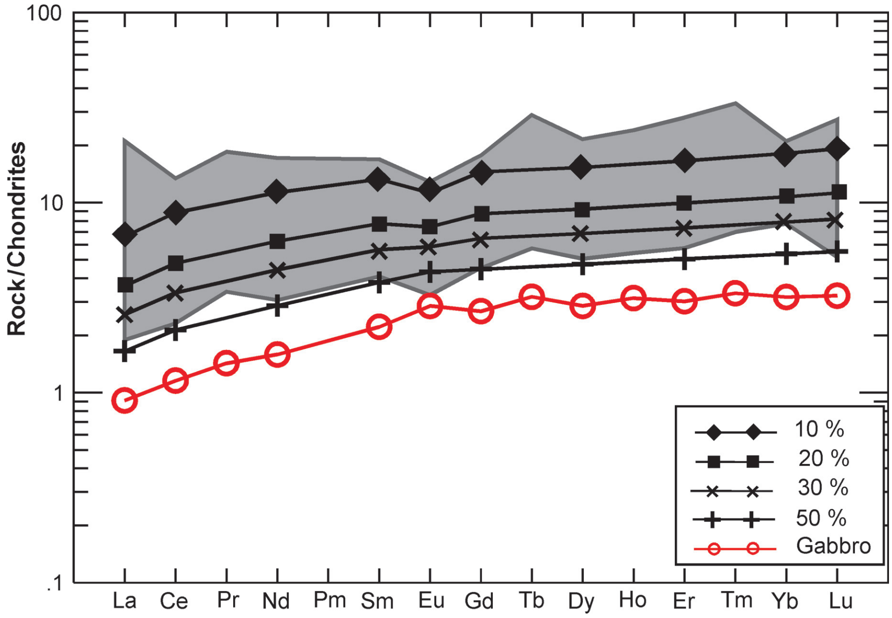

Fig. 11. Model REE patterns of plagiogranite generation by fractionation of a gabbro parent (Sample Eld 14e, Table 1) with a mineral assemblage of $0.1_{olivine}+0.5_{plagioclase}+0.3_{clinopyroxene}+0.1_{hornblende}$. Distribution coefficients are from Rollingson (1993).

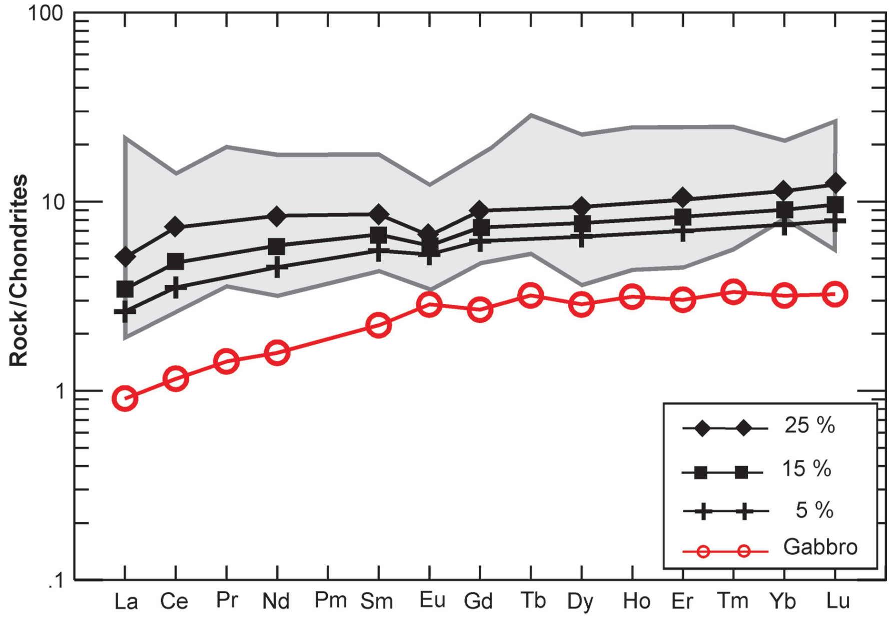

Fig. 12. Model REE patterns of plagiogranite generation by modal equilibrium batch melting of a gabbro parent (Sample Eld 14e, Table 2) with a mineral assemblage of $0.1_{olivine}+0.5_{plagioclase}+0.3_{clinopyroxene}+0.1_{hornblende}$. Mineral/liquid partition coefficients for REE are from Rollingson (1993).

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